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Water Rock Interaction [WRI 14]

The effects of brine concentration on the formation of residual water

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Abstract

Geological storage of CO_2 in deep saline aquifers is achieved by injecting CO_2 into aquifers and displacing the brine. Although most of the groundwater is displaced, some residual groundwater remains in the rock pores. We conducted experiments to investigate the formation process of residual water. Rock samples were saturated with brines of different concentrations. CO_2 was injected into the samples at aquifer temperature and pressure, and the drained water was measured. The results show that the groundwater drainage was slower and the irreducible water saturation was higher with higher brine concentration. The process of drainage can be classified into three stages according to the drainage flow rates: piston drainage, portable drainage, and dissolved drainage.

Keywords: CO_2 geological storage; supercritical CO_2; residual water; irreducible water saturation; three stages of drainage.

1. Introduction

Saline aquifers are widely spread geologically and have the potential for large CO_2 storage capacity [1]. CO_2 injected into an aquifer will displace the brine but the groundwater will not be completely drained by the injected CO_2 because of the capillary force present during the injection [2, 3].

Experiments of residual gas saturation include those of Suekane et al. [4] who evaluated the maximum trapped CO_2 saturation in Berea sandstones under aquifer conditions. Pentland et al. [5] tested Berea sandstones under the same conditions but with an initial pore volume saturation of 90% supercritical CO_2 (SCO_2) and less than 10% water. They showed that because of the low residual water saturation in their experiment, the residual gas saturation was about 10% higher than in the former experiment. Previous studies of CO_2 sequestration in saline aquifers did not examine in detail the formation process of residual

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water or the effects of varying brine concentrations on the irreducible water saturation. In our experiment we saturated the rock core with deionized water and two different concentrations of NaCl brines (17.5 g/l and 35g/l). Supercritical CO_2 was injected into the rock and the amount of displaced fluid measured at the end of each drainage period after 45 min, 2 h, 3 h, 6 h, 9 h, 12 h, 24 h, 36 h, and 48 h. We observed the formation process of the residual water and examined the effect of the different brine concentrations on this process.

2. Experimental setup and procedure

We used a CO_2 migration physical simulation platform (Fig. 1) to replicate the geological sequestration conditions. The apparatus simulates the gas-phase fluid and liquid-phase fluid seepage flow processes in rock medium.

The complexity of natural rock makes it difficult to analyze the influence of the various factors in the experiment. Therefore, we selected a homogeneous isotropic hydrophilic artificial rock core with a permeability of 2.2 mD, porosity of 14.6%, and dimensions of ϕ50 × 80 mm.

The experiment was carried out at a temperature of 40ºC and pressure of 8 Mpa. At the initial stage of the drainage, the water flow rate at the outlet end was controlled at about 0.006 ml/s and the pressure difference between the upstream and downstream ends of the core was about 0.5 Mpa. The stable CO_2 flow rate was about 0.01 ml/s and the pressure difference between the upstream and downstream ends of the core was about 0.3 Mpa. The pore fluid driven out from the rock pore was collected in the gas-liquid separator and the mass of the fluid was weighed on an electronic balance at the end of each drainage period.

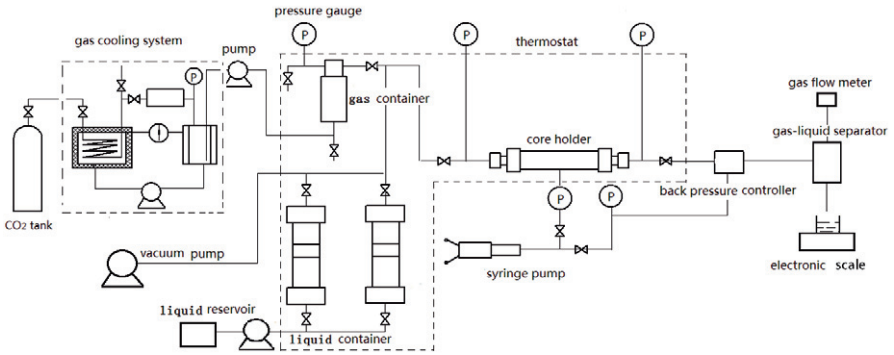


Fig. 1. Schematic diagram of experimental apparatus.

3. Experiment results

The water outflow rate curve measured during the drainage (Fig. 2a) shows that during the initial stage that lasted 45 min, large amounts of water (~0.006 ml/s) flowed from the outlet. Most of the water was driven out of the rock core at this stage. After about 45 min of drainage the ‘breaking point’ was reached, as indicated by the detection of escaping gas at the outlet end. At this point the water flow rate decreased sharply and the decreasing trend was maintained for 48 h (Stage 2). After 48 h the flow rate diminished, and remained very small value over a long period of time (Stage 3).

The experiment was performed for rock core saturated with deionized water, 17.5-g/l NaCl brine, and 35-g/l NaCl brine (Fig. 2b). At the breaking point (~45 min), the concentration of residual water relative

to the initial saturation was 36.74%, 44.72%, and 49.02% for the water, 17.5g/l brine, and 35g/l brine, respectively. The flow rate decreased during the second stage and after 48h reached the point of irreducible water saturations of 26.68%, 26.95%, and 28.85% for the deionized water and NaCl brines of 17.5g/l, and 35g/l, respectively.

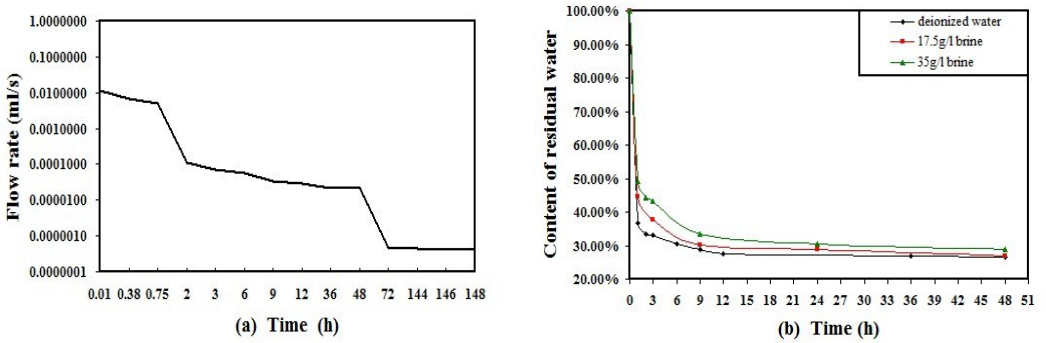
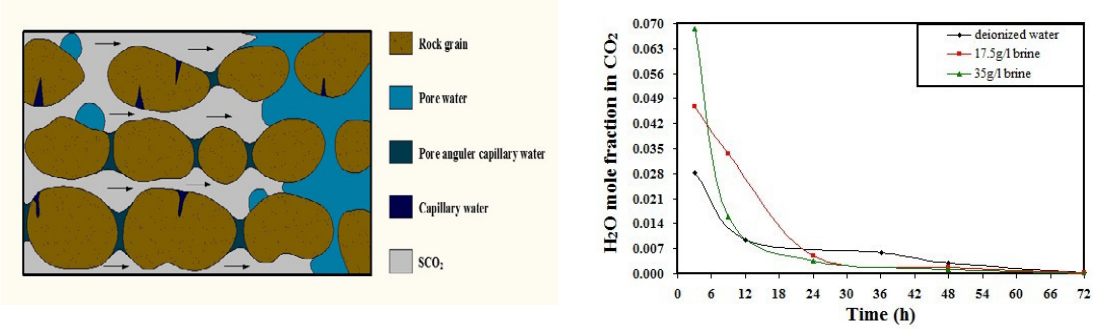


Fig. 2. (a) Water outflow rate of displaced fluid; (b) Residual water content of the three brine concentrations.

4. Analysis of the results

During the first stage of drainage (0–45 min) most of the pore fluid is driven out from the rock pore by supercritical CO_2 according to the capillary model (Fig. 3a). This stage is accordingly named the Piston Drainage Stage. The capillary action during the first stage does not displace all the pore water. Small amounts of pore water remain on the surface of the rock grains and some water is retained as pore angular capillary water between the grains. This residual water may be removed by the hydraulic gradient or by the thrust of the CO_2. The water droplets removed in these processes then leave the rock pore enveloped in CO_2. Because of their minimal weight these water droplets may not fall into the gas-liquid separator but will disperse in the air. The mass of this water can be calculated as the difference between the mass of the water removed from the rock pore and that collected in the gas-liquid separator. This stage is called the Portable Drainage Stage.

The third stage of rock drainage starts when the H_2O mole fraction in the CO_2 is less than or equal to 0.002 (based on solubility data of H_2O in CO_2 at 40ºC and 8 Mpa [6]). The capillary water in the cracks of the rock grains and the stable pore angular capillary water between the grains cannot be driven out during the Piston Drainage and Portable Drainage stages. In the third stage, called the Dissolved Drainage Stage, the residual capillary water may be driven out by dissolution in the supercritical CO_2. The amount of residual water is very small and the process lasts for a very long time. The starting point of the Dissolved Drainage Stage can be determined by the H_2O mole fraction in the CO_2 shown by the drainage time curve in Fig. 3b. After 3h, the mole fraction of H_2O in CO_2 was smallest for the deionized water and higher for the 17g/l NaCl brine, while the 35g/l NaCl brine had the highest mole fraction. At this point, the H_2O mole fraction in CO_2 was in a state of super-saturation in all three experiments. The mole fraction decreased gradually as the drainage continued. After 48 h, the H_2O mole fraction was highest for the deionized water and smallest for the 35g/l NaCl brine. The H_2O mole fraction for the 17.5g/l NaCl brine was between these two values. The H_2O mole fraction in CO_2 after 48 h was within the solubility in all three experiments. After 48 h all three experiments had proceeded from the Portable Drainage Stage to the Dissolved Drainage Stage.



(a) (b)

Fig. 3. (a) Capillary model of the formation of residual water; (b) The curve of H_2O mole fraction in CO_2 versus drainage time.

5. Conclusions

When CO_2 is injected into deep saline aquifers residual water remains in the rock pore. The amount of residual water will not only affect the trapping capacity of structural and stratigraphic traps, but also have a strong influence on the residual-gas traps. The drainage process and the amount of residual water will change with different concentrations of brine.

Our experiments show that the brine concentration had a considerable effect on the formation of the residual water. The drainage took longer with the higher brine concentration than with the lower concentration and the amount of residual water of high concentration was larger than that of the lower concentration in all the stages.

We divided the drainage process into three stages according to the water flow rate: the Piston Drainage Stage (0–45 min), Portable Drainage Stage (45 min–48 h), and the Dissolved Drainage Stage (48 h–onwards).

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